BELLCOMM. INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 07086

SUBJECT: Electrical Power System for AAP Dry Workshop - Case 620

DATE: July 29, 1969

FROM: B. W. Moss

ABSTRACT

The Electrical Power System (EPS) for the Wet Workshop and Dry Workshop configurations are described and compared based on previously established capabilities and loads. System margins are determined for the Wet Workshop configuration

AM	EPS	+ 960 w
ATM	EPS	+ 540 w.

For the Dry Workshop configuration, these margins are

AM	EPS	+ 463 w
ATM	EPS	+1290 w.

The advantages and disadvantages of integrating the AM EPS and ATM EPS using AM hardware are given as an example. The margin for this integrated system is +1338 w. Other approaches to power system integration are possible but are not discussed here since the final choice will require a more detailed study.

While some modifications are required to the ATM EPS to accomplish this, greater flexibility, improved efficiency, and integrated power management result.

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MEMORANDUM FOR FILE

INTRODUCTION

A proposal has recently been made for the use of a Dry Workshop configuration for the Apollo Applications Program rather than the Wet Workshop which is the baseline configuration. The Electrical Power System (EPS) extant on the Wet Workshop is proposed to be used, with minimum modifications, on the Dry Workshop. Both systems are described and compared and a third integrated system is proposed based on use of AM hardware which offers some significant advantages. Several approaches are possible for this integrated system design:

a) ATM EPS unmodified and AM EPS modified to match characteristics

b) AM EPS unmodified and ATM EPS modified to match characteristics

c) A new design for an integrated system.

Many considerations will affect the final choice.

WET-WORKSHOP SYSTEM

The AAP Cluster for the 56-day ATM solar astronomy mission consists of an Orbital Assembly (OA) of the wet-launched S-IVB Orbital Workshop (OWS), Airlock Module (AM), and Multiple Docking Adapter (MDA), the Command and Service Module (CSM), and the Lunar Module Ascent Stage (LM-A) and Apollo Telescope Mount (ATM). Electrical power is supplied to the various loads by Fuel Cell Assemblies (FCA) on the CSM, a Solar Array/ Battery (SA/B) system on the OA, and a SA/B system on the ATM.

The characteristics and performance of these various systems have been described in many documents and, for convenience, are summarized on Table I for the AM EPS and Table II for the ATM EPS. The FCA characteristics are not summarized because they are limited by reactant supplies to an average of 1800 watts over the total mission duration. They are, however, capable of supplying 3700 watts maximum for peak load conditions.

If we consider now the loads and the sources which supply them (Table III), we find that the minimum average system margins are 960 w for the AM EPS and 540 w for the ATM EPS. These margins are based on minimum continuous bus power from the SA/B systems ($\beta=0°$) and on mission average loads. During any one orbit, higher loads can be sustained by increased depth

Table I

AM EPS CHARACTERISTICS

AM EPS	
Solar Array (Reference 1)	
Area	1360 ft^2
BOL Power Rating	11900 w
EOL Power Rating (8 mos.)	11440 w *
Battery (Reference 2)	
AH Rating	33 AH
WH Recharge Efficiency	0.677
Charger (Reference 2)	
Type	Buck
Efficiency	0.95
Regulator (Reference 2)	
Type	Buck
Efficiency	0.95
Bus Power	
Minimum Continuous (β=0)	3920 w **
P_{SA}/P_L (Reference 3)	2.55
Distribution Loss	15 %

* Degraded at 1/2 % per month

** Includes penalty for bus split 9.1 %, regulator mismatch 164 w.

Table II

ATM EPS CHARACTERISTICS

ATM EPS	
Solar Array (Reference 3)	
Area	1200 ft^2
BOL Power Rating	10480 w
EOL Power Rating (2 months)	10375 w *
Battery	
AH Rating	20 AH
WH Recharge Efficiency (Reference 4)	0.70
Charger	
Type	Buck
Efficiency (Reference 4)	0.96
Regulator	
Type	Buck/Boost
Efficiency (Reference 4)	0.875
Bus Power	
Minimum Continuous (β=0) (Reference 8)	3600 w **
P_{SA}/P_L	2.65
Distribution Loss (Reference 4)	14 %

* Degraded at 1/2 % per month

** Based on thermal limit for CBRMs

Table III

WET WORKSHOP CONFIGURATION

SYSTEM MARGINS

Requirements			
CSM (References 1 & 5)			2250 w
AM (References 5 & 6)			777
MDA (References 5 & 6)			251
OWS (References 5 & 6)			1212
	Total Requirement		4490 w
Power Available			
FCA		1800	
AM EPS (Reference 1)		3650 *	5450
	System Margin		+ 960 w
Requirements			
ATM (Reference 7)			2310 w**
LM-A (Reference 7)			750
	Total Requirement		3060 w
Power Available			
ATM EPS (Reference 8)			3600
	System Margin		+ 540 w

* Includes penalty for ATM array shadowing
** Averaged over one orbit

of discharge (DOD) of the batteries during that orbit and replenishment of charge during subsequent orbits, and by operation of the CSM FCA's at higher than the average level.

DRY-WORKSHOP SYSTEM WITH MINIMUM MODIFICATIONS

The Dry Workshop (DWS) for AAP consists of a dry launched S-IVB Workshop, Airlock Module, Multiple Docking Adapter, and Apollo Telescope Mount with a Command and Service Module completing the Cluster. Various modifications would be made to these modules to go from the wet to dry Workshop configuration, but these will not be discussed in detail in this paper. However, some general ground rules can be stated that will affect the electrical power requirements, distribution, and availability. These include

1. use of the present AM EPS, essentially unmodified,
2. use of the present ATM EPS, essentially unmodified,
3. no interconnection of the two systems because of fundamental differences in characteristics,
4. shutdown of CSM FCAs after docking,
5. elimination of the LM-A, and its associated loads,
6. relocation of ATM Control and Display Console in the MDA,

and 7. operation of the CSM in a dependent mode.

As a result of these ground rules, the loads and system margins shown on Table III become as shown on Table IV.

INTEGRATED DRY-WORKSHOP SYSTEM

Suppose we take exception to the ground rule of no interconnection of systems, and attempt to make the two systems similar in characteristics so that parallel operation is possible. To accomplish this, the regulators should have the same output voltage and the same "droop" characteristic so that load sharing and voltage tracking can occur. Since the AM EPS operates at a somewhat better overall efficiency than the ATM EPS, matching the ATM EPS characteristics and those of the AM EPS is desirable. Because the AM Regulator is "buck" only and the ATM Regulator is "buck-boost," the losses in the AM Regulator are lower and, therefore, substitution of the AM Power Conditioning Group (PCG) for the ATM Charger-Battery-Regulator Module (CBRM) is recommended.

Table IV

DRY WORKSHOP WITH MINIMUM MODIFICATIONS

SYSTEM MARGINS

Requirements		
CSM*		750 w
AM (References 5 & 6)		777
MDA (References 5 & 6)		251
ATM C&D Console (LM-A load) (Reference 9)		197
OWS (References 5 & 6)		1212
	Total Requirement	3187 w
Power Available		
AM EPS (Reference 1)		3650
	System Margin	+ 463
Requirements		
ATM (Reference 7)		2310 w
	Total Requirement	2310 w
Power Available		
ATM EPS (Reference 8)		3600
	System Margin	+ 1290 w

* Bellcomm Estimate

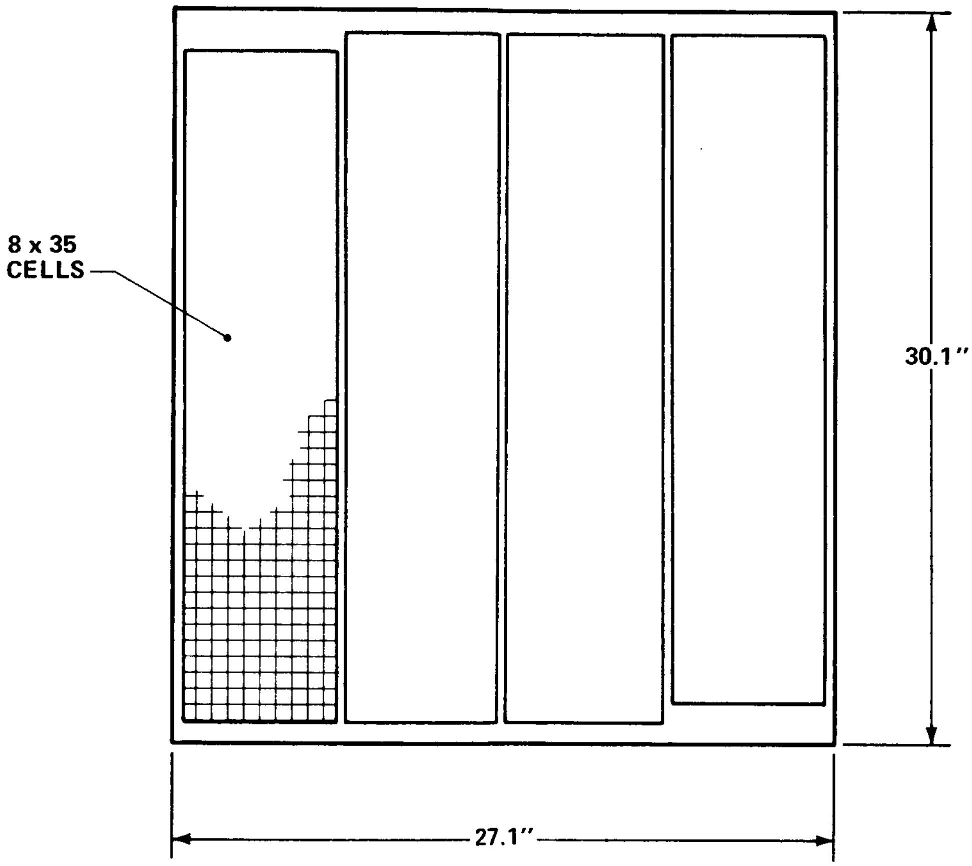
To use a buck regulator, however, it is necessary to have a higher battery voltage than is available from the ATM Battery (24 cells). This implies the use of the AM Battery (30 cells). At this point, the requirement for substitution of the AM Charger for the ATM Charger is obvious.

The remaining problem to be attacked is the ATM Solar Array configuration. The easiest approach would be to substitute OWS Solar Array modules (Figure 1) for ATM Solar Array modules (Figure 2)--30 OWS modules in parallel for each PCG (AM battery, charger, and regulator). Unfortunately, the OWS modules are not compatible with the mechanical, structural, and geometric design of the ATM wings. In order to substitute OWS Solar Array modules for ATM modules extensive modifications would be required to the solar wing and ATM Structure which would probably result in changes in the dimensions of the stowed solar array. It would be desirable to make minimum changes, if any, to the ATM wings. The arrangement of modules on a typical panel of the ATM array and of the panels on a wing is shown on Figure 3.

An alternative would require modification to 20% of the ATM modules used. This modification is shown on Figure 4. One such module would be required for every four unmodified modules. Properly connected (one-fourth of each modified module (28 series cells by 6 parallel cells) in series with a regular module (114 series cells by 6 parallel cells)), each panel of 20 modules would provide 16 equivalent modules (142 series cells by 6 parallel cells). In order to match the OWS Solar Array performance characteristics in which 30 parallel modules (142 series cells by 8 parallel cells each) are connected to one PCG, we must now so connect the ATM modules as to provide 240 parallel cells (8 x 30). This can be accomplished by using 40 equivalent modules or 2 1/2 panels to feed one PCG.

The question of sizing of the new ATM EPS remains to be answered. Since we will now have an integrated electrical power system in which batteries, chargers, and regulators are identical and interchangeable, we can consider both arrays (OWS and ATM) and all PCGs as a single integrated system instead of two independent systems.

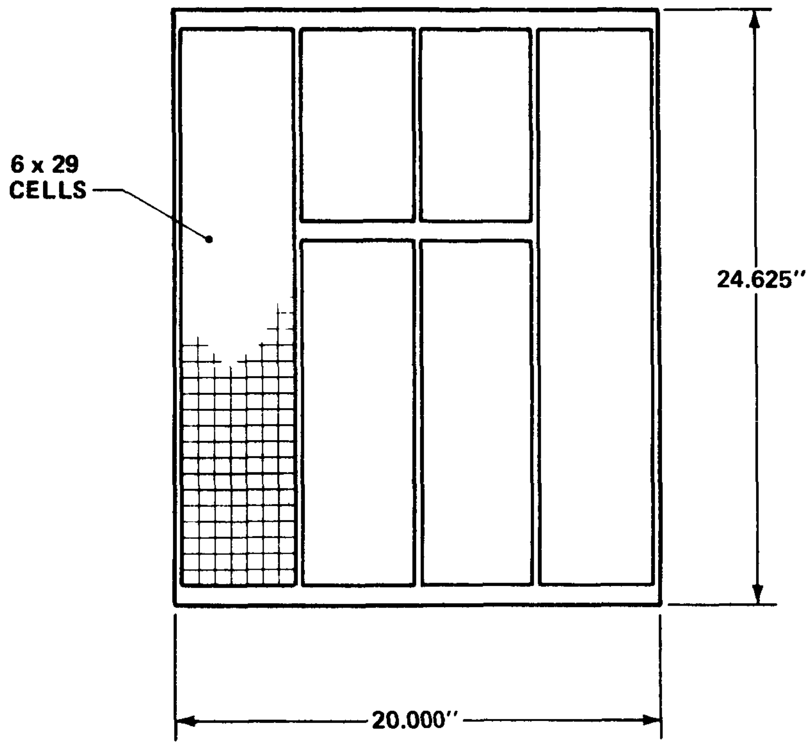
Each PCG will be supplied by 30 OWS modules rated 50.4 watts each (at air mass zero(AMO)) or 50 ATM modules rated 30.3 watts each (at AMO). In either case, the total array power, P_{SA}, is 1515 watts per PCG. Using a value for $P_{SA}/P_L = 2.55$ for the efficiencies given for the AM PCG, we



50.4 W/MODULE
@ 55° C AMO

1136 CELLS TOTAL
8 IN PARALLEL
142 IN SERIES

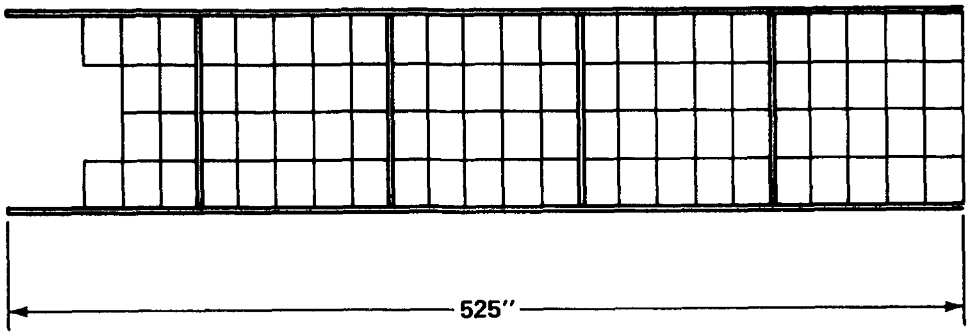
FIGURE 1 - OWS SOLAR ARRAY MODULE



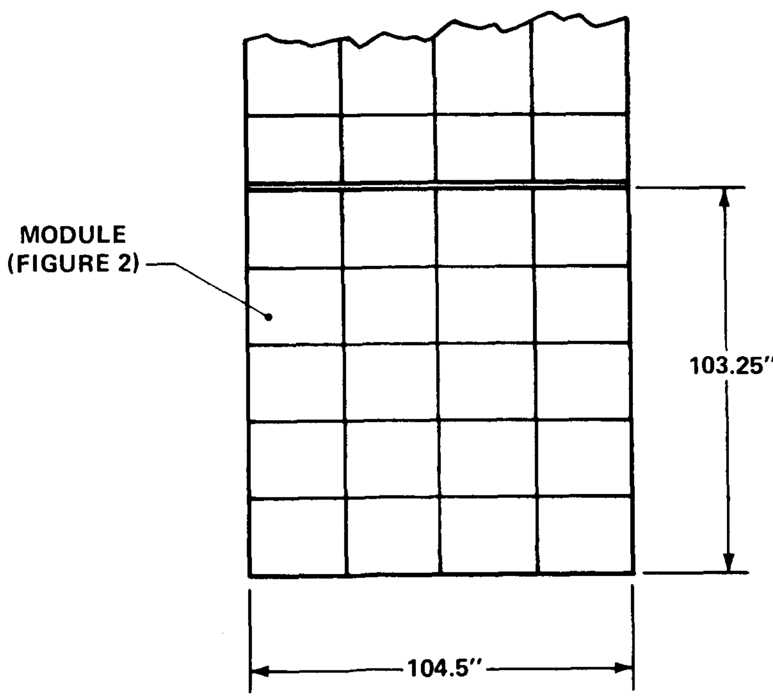
30.3 W/MODULE
@ 55° AMO

684 CELLS TOTAL
6 IN PARALLEL
114 IN SERIES

FIGURE 2 - ATM SOLAR ARRAY MODULE



SOLAR WING



PANEL

FIGURE 3 - ATM SOLAR ARRAY

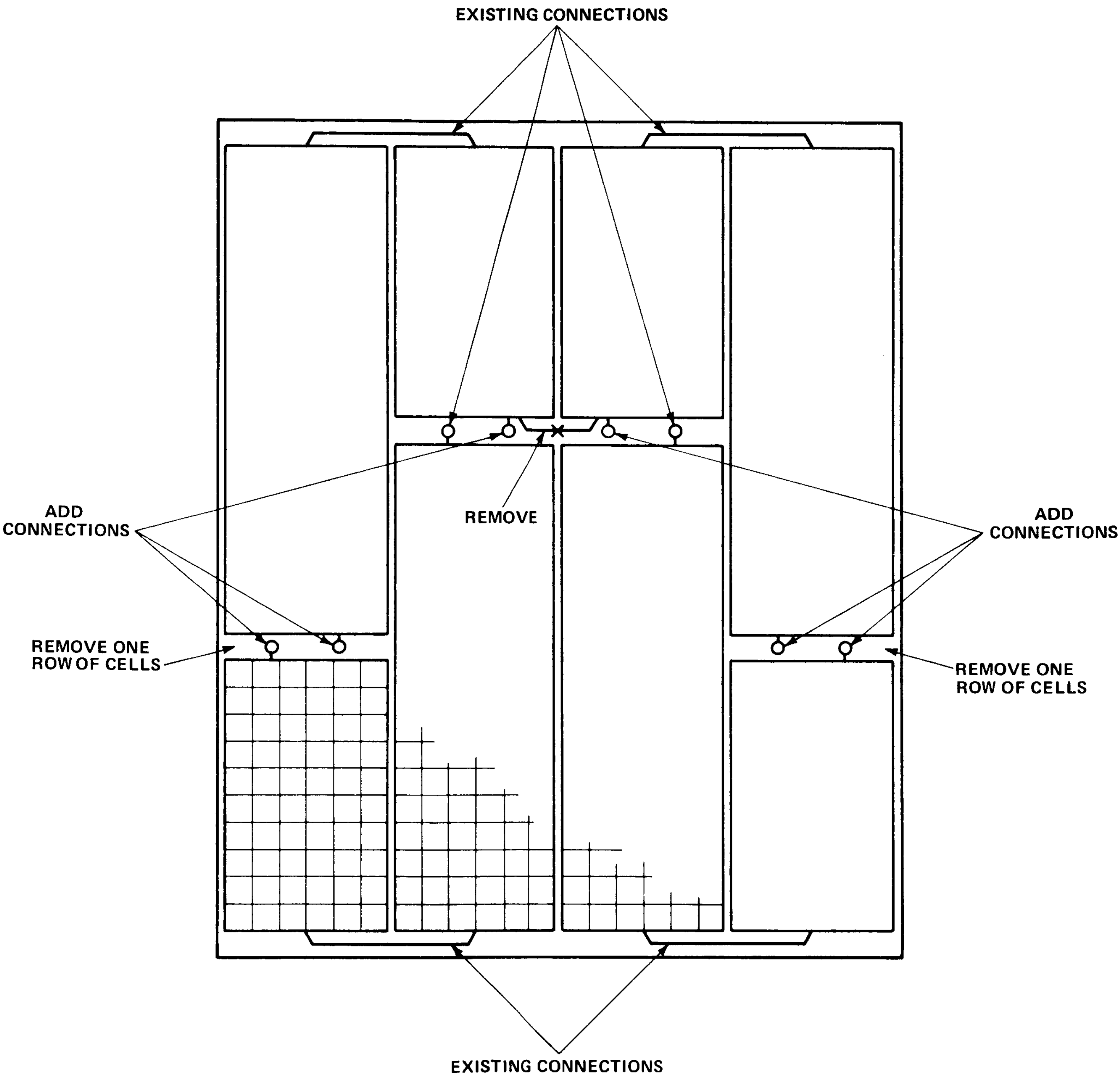


FIGURE 4 - MODIFIED ATM SOLAR ARRAY MODULE

find each PCG/Array combination rated for 594 watts minimum continuous bus power at $\beta = 0°$. Using the loads given on Table IV for the Dry Workshop, we find a total requirement for 5497 watts. If we allow 20% system margin, we develop a need for a minimum source capability of 6595 watts. At 594 watts per PCG, this represents a need for 11.1 PCGs. It is, therefore, proposed that the total system consist of 12 PCGs supplied by 1360 ft^2 of solar array on the OWS (360 OWS modules) and 684 ft^2 of solar array on the ATM (200 ATM modules). The arrangement of the solar arrays is shown on Figure 5.

The total system performance can now be determined and is shown in summary form on Table V. The system margin under various assumptions is shown on Table VI. Considerable discussion has taken place relative to the propriety of imposing the penalties shown on Tables V and VI for bus-split and for regulator mismatch. The purpose of considering these penalties in the determination of system capability is to insure that adequate power will be available under maximum load conditions.

Reference 2 specifies the existence of a "fine adjustment" on each regulator so that accurate load sharing can be assured at maximum load. The regulator mismatch penalty is, therefore, a fiction under maximum load conditions. While it may exist under less than maximum load, the effect is of no consequence then since more power is available than is required.

The bus-split penalty assumes that the two buses will not be loaded equally. The system must be sized so that the heavier loaded bus has half the system capability. The lighter loaded bus, then, is underloaded and this extra capability is unavailable. This, too, is a fiction because load assignments can be made so that, at maximum load, this difference is bus loading is insignificant. At less than maximum load, each bus could handle up to one-half the system capability with no penalty. From Table VI, then, the system margin, ignoring these penalties, is over 1300 watts or almost 25 percent. But if both penalties are included, which is unrealistically conservative, the system margin is still 470 watts or better than 8.5 percent. Both of these margins are determined under the condition of minimum available power ($\beta = 0°$).

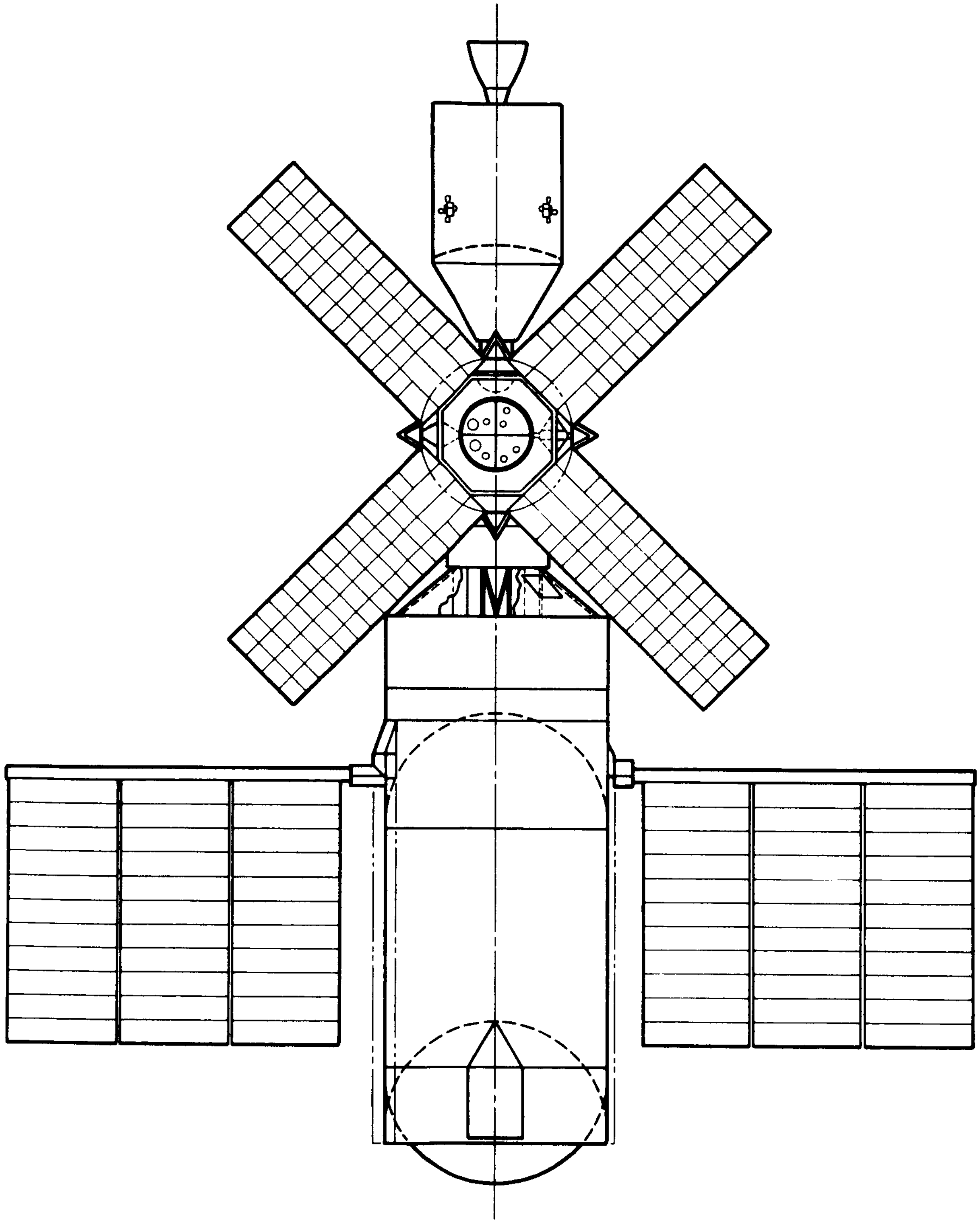


FIGURE 5 · SOLAR ARRAY ARRANGEMENT

Table V

PERFORMANCE OF INTEGRATED SYSTEM

System Performance

OWS Solar Array			
240 modules @ 50.4 watts		12100	
ATM Solar Array			
200 modules @ 30.3 watts		6060	
Total BOL Array Power		18160	
1/2%/month degradation (8 months)		730	
Total EOL Array Power		17430	w
P_{SA}/P_L = 2.55 (Reference 3)			
Minimum Continuous Bus Power (β=0)		6835	w
Penalties			
Bus Split (9.1%)	622 w		
Regulator Mismatch			
20.5 w/reg	246 w		

Table VI

MARGINS FOR INTEGRATED SYSTEM

System Margin

Available Power

No penalties-----------------------------------6835

Regulator Mismatch Penalty only-------6589

Bus Split Penalty only-------6213

Both Penalties------5967

Loads (Table IV)

CSM	750				
AM	777				
MDA	251				
ATM C&D	197				
OWS	1212				
ATM	2310	5497	5497	5497	5497
System Margin		+ 470	+ 716	+1092	+1338

System Comparison

There are some obvious advantages in the approach of minimum modifications to the systems as designed for the Wet Workshop Configuration:

1. no significant changes are required except for some minor wiring changes,

2. an enormous system margin will exist (463 watts or 14.5 percent on the AM EPS; 1290 watts or 55.8 percent on the ATM EPS).

Along with these, however, go some serious disadvantages

1. power management of the two systems is inflexible and at two different locations - AM EPS in AM, ATM EPS in MDA,

2. interconnection of the AM and ATM EPSs is not possible,

3. contingency operation is difficult if not impossible because of the differing characteristics, and

4. the ATM EPS operates at a lower efficiency than the AM EPS.

The advantages of the integrated EPS based on AM hardware are

1. a more flexible, unified power system with no need for switching and complex interconnections to support emergency power transfer (power sharing between systems ceases to be a problem),

2. greater system efficiency,

3. integrated and centralized cluster power management and system monitoring,

4. reduction in size of the ATM Solar Array and removal of ATM CBRMs, which results in reduced weight and inertia of solar array wings and reduced structure on the rack,

5. reduction in size of the ATM Solar Array which eliminates the shadowing of the OWS Solar Array, reduces the ATM Star Tracker occultation problem, and reduces the ATM antenna shadowing problem, and

6. ATM Thermal Control System may be operated during pre-activation period with much greater latitude on EPS limitations because of greater capacity of integrated system.

Attendant with these advantages, however, there are some "costs" or disadvantages

1. some of the ATM Solar Array modules must be modified (20 percent of them),

2. ATM Control and Display Console must be modified to eliminate power monitoring and control functions (add them to the AM power panel) or add all PCG monitoring and control functions to the ATM (eliminate them in the AM),

3. mounting provisions for the additional batteries, chargers, and regulators must be arranged on the AM, and the AM cooling system must be modified to handle the additional waste heat from the PCGs,

4. more complex cable routing and power distribution will be required both on the ATM solar array wing and throughout the cluster with potential increases in the EMI problems,

5. additional capability will be required in GSE to permit integrated system testing, and

The modification of the ATM Solar Array modules is relatively minor and could be accomplished by rework of those modules already delivered. Mounting for the additional PCGs should be possible without undue difficulty on the AM truss structure (location of present PCGs). The design of the EPS as an integrated system provides redundancy not now available with two different systems (AM PCG & ATM CBRM). The additional cabling required by separation of ATM solar array and associated PCGs is a rather routine problem. All things considered, the advantages of improved efficiency, greater flexibility, and integrated power management far outweigh any disadvantages that accrue to the totally integrated power system.

BWMoss

1022-BWM-ep B. W. Moss

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